J. For. Res. 5: 201–204 (2000)

Short Communication

Damage to Residual Stands from Thinning with Short-span Tower Yarders: Re-examination of Wounds after Five Years

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The current status of wounds on residual trees was investigated and compared with the wound status from five years ago when the stands were thinned and logged. Wound status was defined according to the four levels of severity based on appearance. Several damaged trees were cut for inspection of the wounded areas. Most wounds of a lighter severity level had already healed by occlusion and were no longer evident. Wounds reflecting heavy damage but had healed, were smaller in the horizontal dimension, or width, than those not yet healed. Slight wounds, but with a current status reflecting persistent damage were smaller in the vertical dimension, or length. An inspection of wound sections revealed the development of discoloration in the wood. Only the slight wounds that healed early had no or small discolored areas. The width of discolored areas of wounds in which cambium was still exposed was greater than the original width of the wound. In conclusion, wound width rather than length significantly affects healing or occlusion of wounds.

Key words: logging, residual stand damage, thinning, transition of wounds, wounded wood section

Currently, thinning is the most favorable harvesting method in today's Japanese forestry. Environmental concerns and economic restrictions (high cost of replanting) in the Japanese forest industry prohibit large-scale sales using the alternative clear-cutting method. One possible solution to this situation, is a small logging system suitable for a selective thinning operation using short-span tower yarders, self-propelled carriages, *etc*. When used with a low-standard forest road network, such systems perform cost effective thinning operations even with small sales. However, most logging workers in Japan are not well trained in the thinning-logging operations in dense stands, especially with the single-tree selection. In some cases, a large number of residual trees are damaged through thinning and logging operations. Such wounds may reduce the future value of the residual stands. The Japanese timber market demands very high quality in domestic wood. Even small wounds on residual trees will result in large stains in the wood, and, after some decades, trees with such stains might not be of sufficient value to cover management and harvesting costs.

Damage to residual stands from mechanized thinning operations has been studied in North America by, for example, Ostrofsky *et al.* (1986), Bettinger and Kellogg (1993), and Lanford and Stokes (1995). They examined scars on residual tree boles and analyzed how and to what extent wounds were made through logging operations. Recently, Han and Kellogg (2000) discussed sampling methods for the investigation of residual tree damage. With regard to the change in wound status, Benzie *et al.* (1963) and Ohman (1970) traced the same wounds of northern hardwoods from skidding operations four and ten years, respectively, after the logging. They also evaluated the loss in value of the wood by dissecting damaged trees.

In Japan, reports on residual tree damage through thinning operations have increased since the arrival of modern tracked machines, such as harvesters, in the late 1980's. However, there are few reports on the change of wound status. Suzuki *et al.* (1993) and Suzuki (1996a) investigated the change of wound status through the course of five years through visual inspection of the wound appearance. Sakai *et al.* (1984) and Furutani *et al.* (1987) studied occlusion of wounds one, two, three, and four years old but those wounds were pruned knots which were incurred during development of self-climbing pruning machines.

In the present study, tree wounds from a thinning operation in a typical Japanese man-made forest were investigated, focusing on the transition of their status. Status of the wounds just after thinning, five years previously, was compared with the current status. Status of the wounds inside the wood was also examined by dissecting some sample trees.

Materials and Methods

1 Site description

Five plots were established at the Wakayama Station of the Kyoto University Forests, which is located in the middle part of Japan. Plots 1 and 2 were established and logged in 1994, Plots 3 and 4 in 1995, and Plot 5 in 1996. In 1999, five years after the operation, Plots 1 and 2 were investigated; the other plots will be investigated in 2000 and 2001. All plots are within the man-made forests of sugi (*Cryptomeria japonica*), which is one of the major species for saw timber in Japan. The plots include some hardwoods and momi (*Abies firma*), although they are excluded from the following analysis. Stand density of Plots 1 and 2 was 800–900 trees per ha, and 30% of the trees were harvested in 1994 with a short-span tower yarder. Performance of the logging operations was reported in Gandaseca *et al.* (1996) and Sasaki *et al.* (1996). Figures 1 and 2 depict the arrangement of trees and skylines. After the thinning, there were approximately 80 residual trees in each plot. More details of the plots have been previously described (Suzuki, 1996b).

Suzuki (1996b) reported on the wound status of Plots 1

through 4 shortly after the thinning operation. The report revealed that most of the wounds were caused by extraction rather than felling of the logged trees. More than half of the wounds were on boles of less than 1.5 m in height and few wounds were on boles over 3.5 m in height. Also discussed in the report were the relationships between the arrangement of damaged trees and the skylines, and height and severity levels of the wounds in addition to the aspect of the wounds and the arrangement of the skylines. After Plot 5 was harvested in 1996, Doi (1997) re-examined the result of Suzuki (1996b) adding the data of Plot 5 and suggested a relationship between

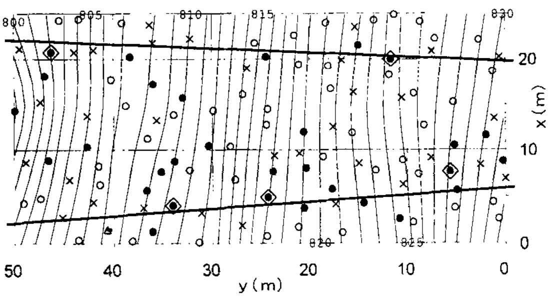

Fig. 1 Plot 1. Thick lines indicate skylines installed at the time of logging; ●, damaged trees; ○, trees with no damage; ×, stump; △, trees other than sugi; —, trees removed before 1999; ◇, sample trees.

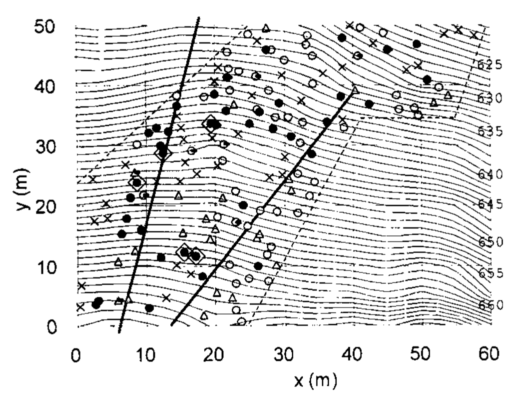

Fig. 2 Plot 2. Broken lines indicate plot boundary. Other symbols are the same as those of Fig. 1.

the logging workers' experience and probability of tree damage.

2 Methods

The position on the bole, dimension, and severity of all wounds were recorded in 1994. Horizontal, (width in cm) vertical (length in cm) dimensions, and area (in cm^2) were calculated from photographs using a digitizer. Severity levels (SL) of the wounds were classified as follows (Ostrofsky *et al.*, 1986; Suzuki, 1996a, b): 1, bark shows evidence of contact but is not broken; 2, bark is broken but cambium is not exposed; 3, bark is broken and cambium is exposed; and 4, both bark and cambium are broken and wood is exposed.

After five years, growth of damaged trees had partially healed the wounds. In the 1999 investigation, the current status (CS) of the wounds was classified into five levels: with 0 indicating no trace on bark and 1 through 4 as described for SL. Wounds were photographed at this time for classification of the CS levels.

Five sample trees were selected, respectively, from Plots 1 and 2 for the inspection of wounds. The selection was made concerning the distribution of severity levels and management plans for the forest. That is, the sample trees were selected from trees for planned salvage cutting such that at least a few wounds from each severity level were contained on the tree boles. After the investigation of the wounds' current status, the sample trees were cut and every wound on the tree was horizontally dissected at midpoint to obtain a representative disk of the respective wound. Then wound sections on the disks were examined to see the progress of occlusion and the development of stains in the wood.

Results and Discussion

1 Change of wound status

Originally, there were 231 wounds on 90 residual trees. Since three trees with a total six wounds had been removed, 225 wounds were investigated. Table 1 shows the CS of wounds that had various levels of severity in 1994. Five years ago most wounds with a CS level of "0" (90) had a SL of 1 (63) or 2 (22). On the other hand, almost 70% of the wounds that were classified as SL 3 or 4 five years previously, had a CS level 3 or 4.

Table 1 Transition of wounds.

Severity Levels (SLs) in 1994	Current status (CS) in 1999						Sums
	0	1	2	3	4	Tree removed	
	Group I ($N = 131$)			Group II ($N = 16$)			
1	63	11	5	5	0	3	87
2	22	13	17	10	1	0	63
	Group III ($N = 22$)			Group IV ($N = 56$)			
3	4	4	12	34	11	1	66
4	1	0	1	7	4	2	15
Sums	90	28	35	56	16	6	231

Notes: CS = 0, no damage; CS or SL = 1, trace of contact n bark; 2, bark broken; 3, cambium exposed; 4, wood exposed.

Growth of trees is generated by cambium. Therefore, wounds with SL 1 or 2, whereby the cambium was not broken, would be expected to heal within a few years. For this paper, the word "heal" means a successful occlusion of wounds such that the growth of wounded trees covers the scars or damaged areas of the wounds. With regard to CS, "healed" can be defined as CS levels 0, 1, and 2, whereby the cambium is not exposed. Therefore, SL 1 or 2 wounds are likely to have a CS level of 0, 1, or 2 and wounds of SL 3 or 4 are likely to have a CS level of 3 or 4; we designated the former as Group I and the latter as Group IV. SL 1 or 2 wounds with CS level 3 or 4 were designated as Group II and SL 3 or 4 wounds with CS level 0, 1, or 2 were designated as Group III (Table 1). There were 131 observations within Group I and 56 observations within Group IV, which were much greater in number than the Group II (16) and Group III (22) observations (χ^2-test, $p < 0.01$).

It can be questioned why the wounds in Group II have not healed while those in Group III healed. Wounds in Group II may have been larger or struck more forcefully at the time of damage, while the opposite situation may have existed with Group III. In comparison of the average wound width among the groups, wound width in Group I was significantly larger than that of Group III ($\alpha = 0.05$; Fig. 3). Successful occlusion may take place within five years in wounds of lesser width.

Average wound length was significantly larger in Group I than in Group II ($\alpha = 0.05$; Fig. 4), demonstrating the same tendency as the average wound area. Group II wounds were at lower SLs in 1994, at 1 or 2, in which healing is considered easy. However, their CS level in 1999 was 3 or 4, indicating a worsening status. One possibility is that the Group II wounds might have been associated with greater damage than wounds in Group I. Note that these wound dimensions were measured with 1994 photographs.

2 Examination of wound section

There were 33 wounds among the 10 sample trees; 8 in Group I, 3 in Group II, 7 in Group III, and 15 in Group IV. Wounds of Groups I and III were occluded. Group I wounds had a wide but thin stained or discolored area, which implies that occlusion was completed immediately after the damage. The three Group I wounds had no discolored areas while, in the remaining 5, the wound sections had discoloration. In the wounds of Groups II and IV, occlusion was proceeding. Discolored areas of the wound were thicker toward the center of the stem. There were a few wounds in Group IV in which occlusion appeared near completion but the discolored areas had spread in both radial and lateral directions during the preceding five years.

To reveal the differences in the spreading of discolored areas between the groups, lateral width and radial thickness of the sectioned wounds were measured (Fig. 5). The ratios of discolored area width to the original wound width as measured in 1994 were compared among the four groups. No significant differences were found ($\alpha = 0.05$). However, it should be noted that the average ratios were larger than 1.0 in Groups II and IV in which the CS level was 3 or 4, indicating that the discolored area had spread laterally from the original width of the wound in which cambium remained exposed. With regard to thickness of the discolored area, the sectioned wounds in Group I had significantly thinner discolored areas than those of the other groups ($\alpha = 0.05$; Fig. 6). Lesser wounds had healed earlier, lessening the chance for stains to develop.

Major use of domestic saw timber in Japan is boards and poles for traditional houses. Knots and discolored areas on timber are the main causes of loss in market value, especially those located near the surface of the wood. Such knots and discolored areas deep within the wood present no problem,

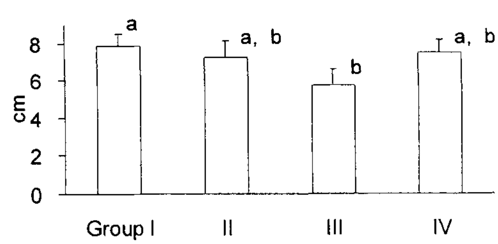

Fig. 3 Width of wounds. Vertical bars indicate standard errors. Lower case letters indicate the result of t-test ($\alpha = 0.05$).

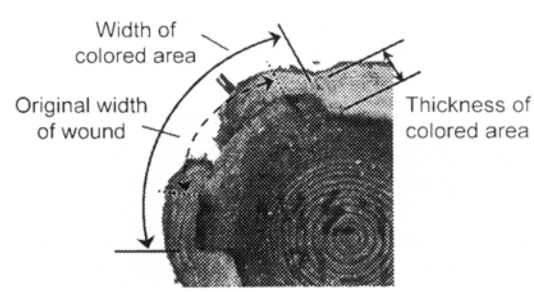

Fig. 5 Example of wound section. Group IV.

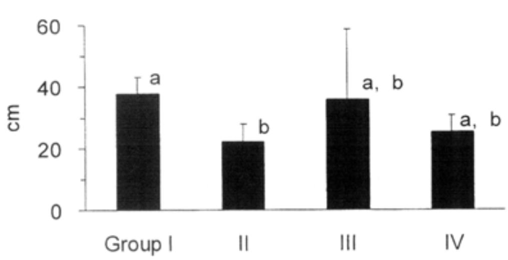

Fig. 4 Length of wounds. Notes are the same as those of Fig. 3.

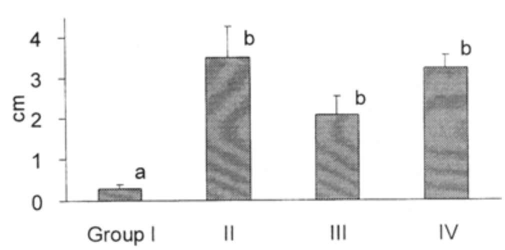

Fig. 6 Thickness of colored area. Notes are the same as those of Fig. 3.

since they do not appear on the surface of saw logs. Only wounds in Group I presented few problems with regard to value loss. Several more years of growth, however, may hide unhealed wounds with a CS level of 3 or 4. Nevertheless, the status of such wounds should be investigated again at a later time.

Conclusions

Damage to residual trees from a thinning-logging operation five years ago was investigated to examine the transition of wound status. Most of the slight wounds had healed while the more severe wounds with exposed cambium were still in a bad state. Of wounds reflecting light damage, 10% had not yet healed. On the other hand, 30% of severe wounds had healed after five years of growth. Such wounds, that is, those that had healed despite their severity had smaller horizontal dimensions than those that had not. An inspection of wound sections revealed that slight wounds that healed had a small discolored section, which would affect saw timber value. Sections of the other wounds revealed spreading of stained areas.

It can be said that the exposure of cambium is crucial for residual tree damage. Slight wounds whereby at most bark is broken but cambium is intact have little possibility to develop inner wood stains. Also, the horizontal dimension of the wound is more important than the vertical dimension for wound healing; the smaller the horizontal dimension, the easier the wound will heal.

In the studied plots, a shot-span tower yarder carried out the logging operations. Contact with skylines resulted in mostly lighter wounds except for trees near the yarder, which swung the tower and skyline. Contact with logged trees caused heavier wounds, especially when the logged trees made unexpected movements, such as falling or bouncing (Suzuki, 1996a; Doi, 1997). Careful choker setting and well designed yarding corridors will help reduce such damage.

There remain three plots to be investigated in 2000 and 2001. Results of the present study will be compared with those of the upcoming investigation of the three plots. The mechanism of wound stain development concerning the cause of damage, practical value loss of damaged wood, and other factors should be studied in that investigation.

The author is indebted to the officers of Wakayama Station of Kyoto University Forests for their help in field investigation.

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* The title is a tentative translation from the original Japanese title by the author of this paper.

(Accepted June 5, 2000)